ELSEVIER
Available online at www.sciencedirect.com
ScienceDirect
Energy Procedia 38 (2013) 250 – 253
Energy Procedia

SiliconPV: March 25-27, 2013, Hamelin, Germany

22.0% Efficient laser doped back contact solar cells

Morris Dahlinger, Barbara Bazer-Bachi, Tobias C. Röder, Jürgen R. Köhler, Renate Zapf-Gottwick, and Jürgen H. Werner

Institute for Photovoltaics and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 47, 70569 Stuttgart, Germany

Abstract

We present the first laser doped interdigitated back contacted solar cells with efficiency η = 22.0%. The cell area is 2 x 2 cm^2, and contains the metallization of both busbars. The high flexibility and spatial resolution of our laser doping process enables local n-type and p-type doping with a precision below 30 µm and avoids any masking process.

Keywords: Laser doping; boron emitter; n-type; back junction; high efficiency; IBC

1. Introduction

Interdigitated back contacted (IBC) solar cells have a high efficiency potential; on an industrial scale they have already been produced with efficiencies exceeding 23% [1]. The cell structure requires locally patterned n-type and p-type doping on the back side of the cell. Usually, this structuring requires a masking with many sub-processing steps. As a consequence, processing is rather complex for this type of cells, leading to increased production cost for the cells. Thus, the increased efficiency has to be carefully balanced with the cost in order to lower the cost per W_p.

Our newly developed laser doping process enables local doping of IBC cells without any masking and is suitable for n-type and p-type doping. Utilizing the high flexibility and spatial resolution of our laser doping process, we fabricate first laser doped IBC solar cells with efficiencies η = 22.0%. In our case, the cell area includes the area of the bus bars.

doi:10.1016/j.egypro.2013.07.274

2. Experimental

2.1. Laser doping

The *ipv* laser doping process bases on nanosecond pulsed laser induced liquid phase diffusion of dopant atoms, such as boron or phosphorus [2-4]. The dopant atoms diffuse from a thin, pre-deposited dopant source into the shallow molten surface layer of crystalline silicon. Our laser doped IBC solar cell concept uses as dopant sources the phosphorus silicate glass (PSG) from standard $POCl_3$ diffusion and a sputtered boron precursor, deposited onto the rear side of the crystalline silicon wafer. Subsequently, a pulsed, frequency doubled Nd:YAG-laser with a wavelength λ = 532 nm and a pulse duration $t_p \approx 50$ ns locally irradiates and thereby melts the samples surface under ambient air conditions. Within few 100 ns, the precursors' atoms diffuse into the laser heated liquid silicon layer. After the termination of the laser pulse, the silicon melt solidifies and recrystallizes epitaxially. The use of a line focused laser beam with a width below 10 µm in short axis prevents defect formation [5,6].

2.2. Solar cell process

Figure 1a shows the process flow of the fully laser doped IBC solar cell. Starting with a one-side textured n-type silicon wafer, a sputtering process deposits a thin boron precursor layer on the rear side of the wafer. Subsequently, our laser doping process irradiates the p^{++}-type doping pattern on the back side of the wafer, forming the emitter. After wet chemical cleaning, an optimized $POCl_3$ furnace diffusion forms a lowly doped front surface field (FSF) on both sides of the wafer. A succeeding second laser doping process locally irradiates/creates the n^{++}-type pattern on the rear side of the wafer. The laser doping utilizes the phosphorus from the phosphorsilicate glass (PSG), grown during the $POCl_3$ diffusion, to form the deep and highly n^{++}-doped back surface field regions. Then, wet-chemical cleaning removes the PSG and the phosphorus precipitates prior the following thermal oxidation. This oxidation acts as a drive-in step for the diffused regions and passivates the surface. The optimized cleaning procedure prior the oxidation ensures a phosphorus surface concentration in the emitter region of about one order of magnitude lower than the boron surface concentration after the oxidation. Plasma-enhanced chemical vapor deposited silicon nitride acts as an anti-reflection coating on the front side and as a reflection coating on the rear side of the wafer. A stack of evaporated Ni/Ag contacts the solar cell through the lithographically opened SiO_2/SiN_x stack. In future, this lithography step for the metallization will be replaced by our patented laser transferred contact process (LTC) [7]. Finally, an annealing step in forming gas atmosphere improves the passivation quality of the SiO_2 layer and decreases the contact resistance.

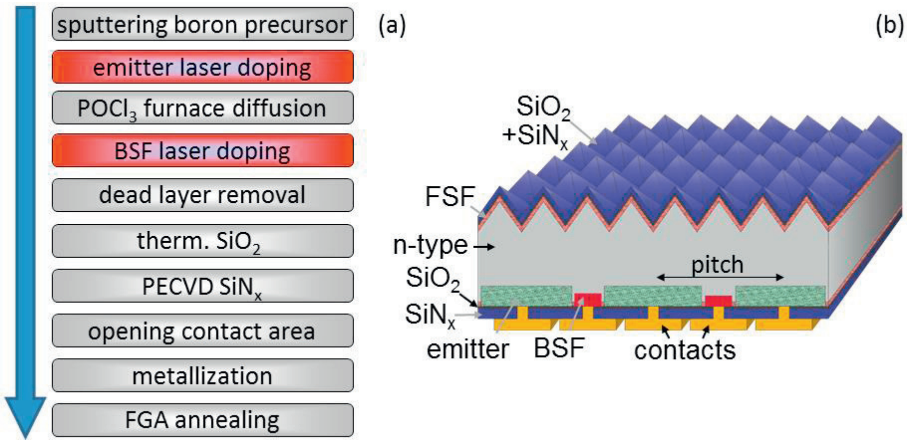

Fig. 1. a) Process flow and b) design of the *ipv* fully laser doped IBC solar cell. The n^{++}-BSF as well as the p^{++}-emitters are fabricated by laser doping without any masking.

2.3. Solar cell results

Figure 1b presents the design of the completed solar cell with SiO_2+SiN_x passivation layer on the front and on the rear of the cell, the FSF, the emitter, the BSF, the contacts and their pitch. The cells with an area A = 2×2 cm² (including the busbars) are fabricated on n-type FZ wafers with a thickness d = 275 µm and a resistivity ρ = 2 Ωcm. Table 1 shows the cell results of the best solar cell of run 1 and run 2 with a pitch p = 1 mm. The pitch describes the distance in which the line shaped doping structure on the back side of the cell repeats. The best cell reaches an efficiency η = 22.0%. The short circuit current density $J_{sc} \approx 41$ mA/cm² indicates a low front surface reflection, a high quality of the FSF, a high bulk lifetime and an excellent light trapping. The fill factor FF = 80.3% is limited by insufficient thick metallization and therefore increased series resistance as well as the resistance appearing between the line shaped contacts, which are located in the center of the BSF and emitter regions. A distributed point contact metallization layout would decrease the series resistance between the contacts and thus improve the fill factor FF. The increased Auger recombination in the highly doped BSF $R_{sh,BSF}$ = 15/sq and the contact areas limits the open circuit voltage V_{oc}. A reduced BSF doping and a reduction of the contact area of the rear side, from now 8.3% to below 2%, will, in future, increase the open circuit voltage.

Table 1. Short circuit current density J_{sc}, fill factor FF, open circuit voltage V_{oc}, and efficiency η for the best cells of the first two runs; the cell area is 4 cm² (including busbars); *certified measurement @ ISE CalLab

Best cell Run	J_{sc} [mA/cm²]	FF [%]	V_{oc} [mV]	η [%]
1	40.9	80.3	663	21.8*
2	41.3	79.8	669	22.0

3. Conclusion

We have realized the first laser doped IBC solar cells with an efficiency up to η = 22.0%. Our laser doping process enables a local n^{++}-BSF as well as a local p^{++}-emitter formation with high spatial resolution without the necessity of any masking. Further optimization of the metallization layout and the BSF-doping will enable us to boost the solar cell efficiency towards 23%, without the use of external busbars. Advanced solar cell concepts will replace photolithographic metallization by our patented laser transferred contact process.

Acknowledgement

The authors thank L. Beisel, H. Moldenhauer, B. Lutz, L. Bauer, and B. Winter for technological support. This work was financially supported by the German Federal Ministry for Environment, Nature Conservation and Nuclear Safety (BMU) under project no. 327519.

References

[1] Smith D. D., Cousins P. J., Masad A., Waldhauer A., Westerberg S., Johnson M., Tu X., Dennis T. D., Harley G., Solomon G., Rim S. B., Shepherd M., Harrington S., Defensor M., Leygo A., Tomada P., Wu J., Pass T., Ann L., Smith L., Bergstrom N., Nicdao C., Tipones P., Vicente D.. Generation III high efficiency lower cost technology: Transition to full scale manufacturing. In *Proc. 38th IEEE Photovolt. Specialists Conf*. Piscataway, New York: IEEE; 2012, p.1594-1597.

[2] Eisele S. J., Röder T. C., Köhler J. R., Werner, J. H.. 18.9% efficient full area laser doped silicon solar cell. *Appl. Phys. Lett.* 2009;**95**:133501.

[3] Röder T. C., Eisele S. J., Grabitz P., Wagner C., Kulushich G., Köhler J. R. and Werner J. H., Prog. Photovoltaics Res. Appl. 18, 505 (2010).

[4] Dahlinger M., Eisele S. J., Köhler J. R., and Werner J. H.. Laser Doped Boron Emitters with Sputtered Precursor. In *Proc. 26th Europ. Photovolt. Solar Energy Conf*., edited by Ossenbrink H, Jäger-Waldau A, and Helm P. München: WIP; 2011, p. 1152-1154.

[5] Werner J. H., Köhler J. R., and Esturo-Breton A.. DE102004036220B4 (26 July 2004).

[6] Ohmer K., Weng Y., Köhler J. R., Strunk H. P., and Werner J. H.. Defect formation in silicon during laser doping. *IEEE J. Photovoltaics 2011*; **1**:183.

[7] Hoffmann E., Röder T. C., Köhler J. R.. Self-doping laser transferred contacts for c-Si solar cells. In *Proc. 38th IEEE Photovolt. Specialists Conf*. Piscataway, New York: IEEE; 2012, p.1059-1062.